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ECOLOGY AND GROWTH OF WHITELEAF MANZANITA WITHIN A PONDEROSA PINE PLANTATION IN SOUTHWEST OREGON

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Abstract

Sclerophyll shrubs such as *Arctostaphyllos viscida* Parry (Ericaceae; whiteleaf manzanita) are often considered obstacles to afforestation. The establishment of conifer plantations in southwest Oregon presents challenging problems for initial seedling survival and subsequent growth. This region is characterized by hot dry summers, cool moist winters, and rocky, shallow soils at low elevations. The growth of competing hardwoods within conifer plantations creates the traditional problem of undesirable competition for the silviculturist. Accumulation of manzanita biomass also contributes heavily to fire hazard while at the same time providing biomass of potential value as biofuel. This study describes productivity of whiteleaf manzanita stands of varying density growing within the confines of *Pinus ponderosa* Dougl. ex C. Lawson var. *ponderosa* (Pinaceae; ponderosa pine) plantations of the same age on poor sites. We explore the ability of this shrub to generate biomass as a potential energy source. Growth prediction equations are for height, basal diameter, biomass per individual, and biomass per hectare by stand density. The accumulated biomass after 14 yr of growth ranges around 43 metric tons/ha, and represents a strong negative influence on the supposed productivity of interplanted pines of the same age. Energy content of biomass amounts to an accumulation rate of 1.6×10^6 megajoules/ha/yr on such sites, indicating a large biofuel potential by age 14 or more. Harvesting the manzanita will also provide a potential benefit to productivity of the pines.

Key Words: *Arctostaphylos viscida*, biomass, competition, growth habit, manzanita, stand density, yield.

Growth equations for sclerophyllous shrubs are rare, as are reports of their value as resources. The search for energy sources in non-commercial forest species may have potential for exploitation both for fuel, and also for benefiting commercially valuable conifers. We examine growth patterns of whiteleaf manzanita on hot, dry sites in southwest Oregon as a function of stand density and age following spacing and weed control. These equations are one part of a multiphased project demonstrating the impact that indigenous hardwood competition has on the supposed productivity of conifer plantations in this region. Current interest in biomass suggests further interpretation of these data toward potential utilization.

Whiteleaf manzanita is a common sclerophyll shrub indigenous to southwest Oregon. It regenerates prolifically from a seed bank after a major disturbance such as mechanical site preparation prior to planting conifer plantations. This species is abundant in interior sites at low elevations through much of southwest Oregon and mid-elevations in much of California west of the summit of the Sierra Nevada Mountains. It may be considered a weed species when mixed with conifer plantations (Newton and Cole 2008), but we here evaluate its role as a potential resource. Toward this end, we quantify the growth of whiteleaf manzanita within young ponderosa pine plantations and document its potential role as a biomass source.

The whiteleaf manzanita data presented here represent the first long-term stand-based dataset for this species while under management. It describes the growth response of whiteleaf manzanita growing at densities of 1700 to 27,000 shrubs per hectare within the confines of a ponderosa pine plantation in southwest Oregon. We summarize the history of the study below, relying on allometrics for individual plants from other studies of whiteleaf manzanita in the area that adapt growth data to biomass (Latt 1985; Hughes et al. 1987; Minore et al. 1988).

Materials and Methods

The research areas for this study are nested within three mixed conifer plantations growing on mechanically cleared shrub lands in the Applegate Valley of southwest Oregon (for detailed site descriptions, see White and Newton 1989). The original design of these plantations was to provide an opportunity to study competition and growth of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) and ponderosa pine seedlings under various competition levels of whiteleaf manzanita and herbs. The original conifers were thinned to 14 ponderosa pine and 6 Douglas-fir per treatment, a density that offered negligible competition during the first five years, but an increasing amount later. Most of the planted Douglas-fir succumbed to moisture deficiency in their seventh and eighth year as a result of unusually high summer temperatures and the superior moisture extraction and stress tolerance of whiteleaf manzanita.

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Our study uses a randomized block design with three replications in each of which are six 0.04-ha square plots containing six different densities of shrubs in a randomly located geometric progression of shrubs per hectare, separated in density by a factor of 2 from highest density to lowest. Treatment designation is based on spacing between individual manzanitas plants, in feet, square spacing equivalent. Treatment 2, for example reflects spacing of 2 × 2 feet (60 × 60 cm; 27,000 shrubs/ha) and treatment 8 represents 8 × 8-foot spacing (240 × 240 cm; 1700 shrubs/ha).

Within each plot, a subsample of 25 shrubs in clusters of 5 was selected for repeated measurement in a systematic sample with location at a random starting point. All shrubs were measured at ages 3, 4, 5, 7, 8 and 14 yr, the age span in which they had full crowns. Measurements in year 21 indicated severe suppression and crown dieback under influence of ponderosa pines, and are excluded from our analysis. All shrubs and pines were established the same year.

All replications are within 4 km of each other, centered at approximately 42°45′N, 123°02′W, and 640–750 m elevation (Delorme Mapping Company 1991). All sites are in southern Jackson Co., Oregon, and are on southwest or southeast aspects with approximately 10–20 percent slope.

The soils at two replications vary between 50 and 80 cm deep, with local deep spots up to 150 cm. Most are clay loam of the Vannoy soil series. The soils at the third replication appear more productive and are of the Caris-Offenbacher soil series (Stearns-Smith and Hann 1986). These soils are gravely loams with the same depth as the Vannoy series. The geologic parent material for all three replications is of metamorphic-sedimentary origin. Original estimated conifer growth was Site V or poorer for Douglas-fir (height at 50 yr $<$17 m, per McArdle et al. 1961) and Site IV or poorer for ponderosa pine (height $<$13 m at 50 yr, per Meyer 1938). Height and breast height age measurements of local dominant trees places the site index between 12 and 27 m at 50 yr. Adjacent stands of whiteleaf manzanita roughly 70 yr old range between 3–4 m tall, with some stems reaching 180 mm diam. at the base, indicating productive sites in terms of adaptation of this manzanita species. Our stands originally had a component of *Ceanothus cuneatus* (Hook.) Nutt. (common buckbrush.), ordinarily found on less productive sites.

In addition to whiteleaf manzanita, other vegetation includes *Arbutus menziesii* Pursh (Pacific madrone), *Rhus diversiloba* Torr. & Gray (poison oak.), *Bromus tectorum* L. (downy brome), *Galium aparine* L. (bedstraw), *Caucalis microcarpa* Hook. & Arn. (California hedge parsley), *Madia elegans* D. Don ex Lindl. (tarweed), *Verbascum thapsus* L. (common mullein), *Centaurea solstitialis* L (yellow star-thistle.), *Quercus kelloggii* Newberry (California black oak), *Fragaria vesca* L (woods strawberry), and *Epilobium minutum* Lindl. ex Lehm. (willow-weed). These species were removed in the study plots except that herbs were retained at one density of manzanita (13,500/ha) after an initial one-year treatment with hexazinone to permit establishment of the ponderosa pine seedlings.

Annual precipitation varies between 60 and 150 centimeters throughout the region (Stearns-Smith and Hann 1986), these sites are in the driest subregion of southwest Oregon. Approximately 65 to 75 percent of this rainfall occurs between November and February (Hobbs et al. 1992).

The sites of all replications had burned about 1930, resulting in large areas of even-aged whiteleaf manzanita. Scattered ponderosa pine and Douglas-fir occurred in cove sites (draws) nearby. All study sites were cleared in preparation for this research in 1980, following domination by near-pure stands of manzanita for 50 yr.

Site preparation for planting consisted of scarification by crawler tractors equipped with brush blades. Brush was pushed into windrows and burned. The tractor scarification created an ideal germination seedbed for the persistent and abundant seeds from whiteleaf manzanita. Profuse germination resulted in a patchy distribution with some areas producing 500,000 seedlings per hectare (White 1989). After burning the windrows, the area was ripped down to a 45 cm depth with a crawler tractor along the contours at approximately two-meter intervals. Afforestation planting occurred in the spring of 1981 with equal numbers of two-year-old (2 + 0) bareroot Douglas-fir and ponderosa pine stock. Spacing was about 1600 seedlings per hectare. After planting, one site was sprayed with 1.7 kg/ha hexazinone for herbaceous weed control. The other two sites were mulched with 90 × 90 cm laminated Kraft paper impregnated with asphalt. The herbicide treatment had no observable effect on the manzanita or *Ceanothus* germinants, or on the vigor of oak and madrone sprouts.

TABLE 1. SUMMARY OF WHITELEAF MANZANITA (ARVI) TREATMENT INSTALLATIONS. There are three replications of each treatment. [1] Completely randomized within blocks.

Treatment ID	Treatment description[1]	ARVI per ha	Sq. m per ARVI
2	27,000 ARVI/hectare	26,910	0.3716
28	13,500 ARVI/hectare	13,455	0.7432
28h	13,500 ARVI/hectare w/ herbs	13,455	0.7432
4	6720 ARVI/hectare	6727	1.4864
56	3360 ARVI/hectare	3364	2.9729
8	1700 ARVI/hectare	1682	5.9458

Installation of the original study occurred in early spring 1983. Control of manzanita density for the various treatments was with chemical thinning or interplanting natural seedlings. The treatments ranged from zero to 27,000 shrubs per hectare in regular square spacings, using 20-meter-square plots (0.0405 ha; 0.1 acre). Table 1 presents a description of the treatments and densities of manzanita remaining after age 3. At the time of installation, the conifer density ranged from 1050 to 1760 seedlings per hectare depending upon mortality during the first two years after planting. Researchers removed all shrubs other than designated whiteleaf manzanita. Planted manzanita seedlings were wild stock carefully dug up on-site from outside plot boundaries and planted the same day wherever gaps existed in the planned grid spacings. All plots had comparable initial densities of manzanita germinants, thus avoiding the confounding between the probability of establishment and site conditions.

Treatment establishment and subsequent herbaceous weed control involved several chemical applications over a period of years. Initially, researchers covered the desired manzanita and conifer seedlings with soft-drink cups prior to broadcast spraying a mixture of 3.3 kg/ha simazine, 2.8 kg/ha glyphosate, and 3.8 kg/ha 2,4-D. The total volume of this application was 121 liters per ha (White 1989). In early 1984, an additional broadcast spray of 4.4 kg/ha of simazine controlled herbaceous weeds. Oak and madrone sprouts were killed with directed sprays of glyphosate or 2,4-D with care taken to avoid manzanitas.

Whiteleaf manzanita individual-shrub parameters were recorded on permanent samples of 25 shrubs per plot with numbered tags and periodic measurements. Although the measurements did not occur every year after 1985, measurements did occur in 1987, 1989, 1994, and 2002. A small reduction in the number of tagged shrubs over time resulted from natural mortality under intraspecific competitive stress. Owing to widespread dieback of crowns observed in the 2002 measurements that compromised estimates of gross growth, our estimates of biomass here will be limited to the first 14 yr.

Three studies (Latt 1985; Hughes et al. 1987; Minore et al. 1988) developed leaf area and biomass equations for whiteleaf manzanita. The studies by Minore et al. (1988) and Latt (1985) used datasets collected from open-grown whiteleaf manzanita. We used the equations developed by Hughes et al. (1987) as having been derived from shrubs in varying densities of stands rather than individual shrubs. We did not verify with complete biomass measurements of our own, but did consult with Hughes in choice of equations and proximity of his data sources to our study (southwest Oregon).

The variation between growing conditions for the data used to produce the biomass equation (Hughes et al. 1987), and the growing conditions on the treatments in this study may represent a source of error. However, this was the only biomass equation available that approximated the growing conditions found in young conifer plantations, and was selected for suitability to the range of sizes in our study.

Analysis is by non-linear regression, reflecting exponential and logarithmic parameters. Aboveground yield prediction equations are given for whiteleaf manzanita growing at varying densities for 14 yr within a conifer plantation ecosystem. These prediction equations use two independent variables. The first is the number of residual whiteleaf manzanita stems per hectare. The second is the plantation age, which is also the age of the manzanita from seed. Even though these shrubs were measured at age 21, influence of interplanted ponderosa pine confounded yields by causing death to large portions of crowns, an observation that led to rejection of that data set in our yield equations.

For the regressions in this study, the natural log of the manzanita growth parameter and of age was taken before running the regression procedure. Square root transformations helped to emphasize the rapid drop in growth when shrubs are subjected to a small amount of competition. Also, regressions were fit against individual replications rather than treatment means. Residual plots showed independence of data and, therefore, a correct transformation. Each growth regression presented is a single regression of a growth parameter on age and shrub density. The methodology was set forth by the Quantitative Sciences Group of the Department of Forest Science (Sabin and Stafford 1990). With this, we

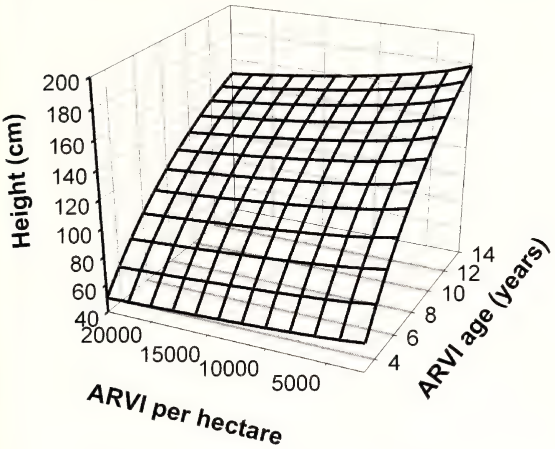

FIG. 1. Height/age relationship as influenced by stand density for whiteleaf manzanita (ARVI). Accelerating height trend with reduced density is highly significant, as is reduced height growth age.

organized the original regressions into a number of terms starting with the main effects and ending with cubed interaction terms. Regressions were then run using the REG procedure within the SAS™ statistical software. This software provides a P-value level for each term in the regression. Terms not achieving a P-value of at least five percent were backed out of the regression and the procedure was run again. After several iterations, all remaining terms had a P-value less than or equal to the five percent level, achieving a good fit to the data.

RESULTS

The growth form of manzanita shrubs on the lowest-density treatments remained open for the first eight years. While open grown, the size of whiteleaf manzanita is predictable for individual shrubs, as described by Minore et al. (1988). Mortality and decreased height growth of individual shrubs became apparent as the treatments reached crown closure, but total growth per hectare continued to increase. The continued rise in growth rate per hectare per year indicates that crowns were coalescing toward full site occupancy beyond age 14 despite mortality of some manzanita.

Manzanita height growth approaches maximum increments within the first 10 yr (Fig. 1). Height increment continues somewhat more rapidly at wide spacings than at the closest spacing in a pattern that suggests even greater heights at wider spacing than shown in our data. This figure shows height is increasing at a decreasing rate, yet adjacent 60+ year shrubs were three to four meters tall in the absence of conifers, presumably having reached their maximum height potential.

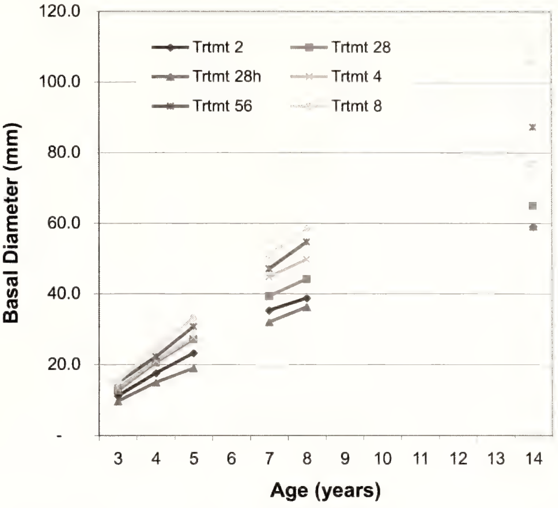

FIG. 2. Basal diameter of whiteleaf manzanita (ARVI) growing at varying densities within ponderosa pine plantations in southwest Oregon, including treatment 28 with herbs. Raw means of all replications. Increasing divergence of height curves with age and differences in shrub density is highly significant.

Diameter growth, hence basal area, is very responsive to spacing (Fig. 2). Treatment 8 (1700 ARVI/ha; 2.4 × 2.4 m spacing), with the least dense manzanita, has the highest basal diameter growth while treatment 2 (27,000 ARVI/ha; 60 × 60-cm spacing), the densest manzanita, has the lowest basal diameter growth but the highest biomass growth. The effect of herbaceous vegetation is evident in treatment 28 with 13,500 ARVI/ha (85 × 85-cm spacing). This treatment is consistently larger in diameter than treatment 28h (85 × 85 cm, with herbs after year 1) that has the same density of manzanita without herbaceous control. Figure 2 shows the negative influence of herbs by being out of sequence in the array of diameter growth curves for the array of stand densities. This aberration does not appear in the response surface of diameter on age and spacing that illustrates interaction of age × density (Fig. 3).

Figure 4 shows the average aboveground oven-dry stem volume biomass per manzanita shrub computed from equations developed by Hughes et al. (1987). Density control strongly influences the net biomass of individual manzanita shrubs. High-density plots produce smallest individuals, but the greatest total biomass (Fig. 5). In view of the large sizes of widely spaced shrubs, one might expect that as self-thinning occurs on dense stands, yields of various densities will merge. However, at age 14 the yields are continuing to diverge in favor of dense stands despite the onset of mortality.

The density of manzanita on all treatments provides a sufficient amount of intraspecific

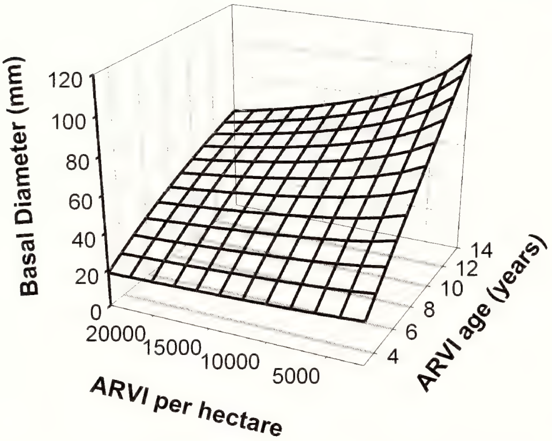

FIG. 3. Basal diameter growth for whiteleaf manzanita (ARVI), by age and initial density. The increase in diameter with decrease in shrub density and increasing age is highly significant.

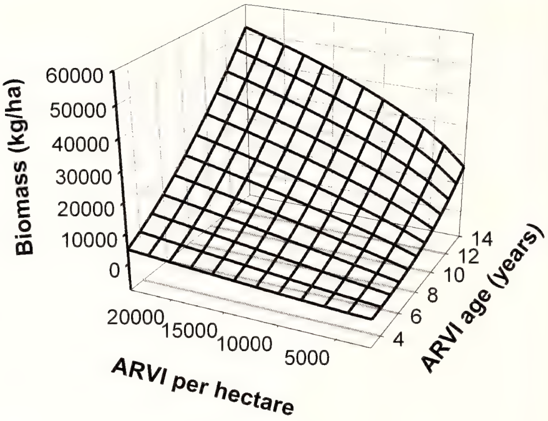

FIG. 5. Oven dry stem biomass per ha for whiteleaf manzanita (ARVI), by age and initial density. Yields are adjusted for mortality. Increase in yield with increasing density of shrubs is highly significant and increases with age.

competition to cause mortality by age 14. Table 2 describes the loss in stems per hectare at several points in the lives of these stands due to mortality at the different treatment densities.

The data from Applegate plots are not of sufficient quantity (25 shrubs per plot) to allow useful regression for changes in shrub populations. Mortality varied sporadically by age depending upon the starting number of manzanita stems. By age 14, the percent mortality roughly aligns with treatment density, ranging from eight percent for the least dense treatment to 21 percent for the most dense. The only treatment with herbs, 28h, had the highest mortality with 24 percent. Although the manzanita have now shaded out all herbs, they still show residual effects of herb competition in their first several years of growth.

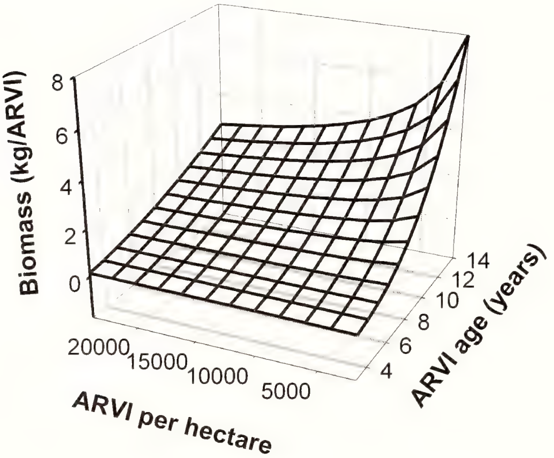

FIG. 4. Oven dry stem biomass for individual whiteleaf manzanita (ARVI), by age and initial density. Increase in biomass with decreasing density of shrubs is significantly greater with lower densities and increasing age.

The various growth parameters are influenced differently by density and its interaction with age. Height growth, (Fig. 1), does not show a large variation between the low and high density treatments although heights are greater with wider spacing. However, basal area, being a squared function of diameter and the largest contributor to biomass, declines sharply with just a small amount of intraspecific competition. Figure 4, oven-dry stem biomass per shrub, demonstrates that a small amount of intraspecific competition triggers a substantial decrease in biomass. When biomass is converted to a per hectare basis, the highest biomass is found in the treatments that have the largest number of stems. This relationship of biomass to density persists through age 14; seen in Fig. 5 where mortality is taken into consideration.

The largest increment in total biomass yield with increasing density from the widest spacing is in the difference between 1682 and 3364 shrubs per ha. Further increments in yield with increasing density are smaller, and are potentially compromised by the apparent relation between density and mortality.

Equations of the response surfaces shown in Figs. 1, 3, 4, and 5 are available from the corresponding author.

DISCUSSION

The whiteleaf manzanita in this study represent a view of potential opportunities for capturing biomass from plants that may otherwise have neutral or negative value, and/or which may be able to produce significant yields on sites too harsh for production of higher-value forest

Table 2. Mortality Summary for Whiteleaf Manzanita (ARVI) at the End of the 2nd, 7th, and 13th Growing Season After Plantation Establishment. [1]Treatment descriptions are given in Table 1.

Treatment ID[1]	ARVI stems per hectare (percent mortality)			
	Initial	Age 2	Age 7	Age 14
2	26,910	26,910 (0)	26,192 (2.7)	21,169 (21.3)
28	13,455	13,455 (0)	12,737 (5.3)	11,482 (14.7)
28h	13,455	13,455 (0)	11,122 (17.3	10,226 (24.0)
4	6727	6727 (0)	6189 (8.0)	5920 (12.0)
56	3364	3364 (0)	3274 (2.7)	3050 (9.3)
8	1682	1682 (0)	1592 (5.4)	1547 (8.0)

species. The manzanita on our plots are growing at densities representative of conditions in both fire-originated stands and in managed conifer plantations within this region. Although manzanita's competitive influence on conifers is well documented (White 1989; Ortiz-Funez 1989; Newton and Cole 2008), the value of manzanita as a bio-fuel is generally unrecognized either as a salvage material or as a crop.

Several studies have described similar yields of shrubs in unregulated densities (Zavitkovski and Newton 1968; Hughes et al. 1987; Minore et al. 1988) as measured either in total yield or on terms of individual shrub growth. Zavitkovski and Newton (1968) displayed with *Ceanothus velutinus* Douglas ex Hook. var. *velutinus* a pattern of upper asymptote in yield at age 14, more or less when not suppressed by conifers. Revisitation of those stands in 2003 finds most of the shrubs suppressed or dead, usually under influence of conifers (Newton personal observation). Our data here originate in uniform stands with a continuum of measurements that terminate at age 14 when yields were increasing rapidly. They are also in full view of older stands with much higher biomass and larger sizes of individual shrubs. These observations suggest the possibility of a potentially much larger estimate of asymptotic maxima.

Our stands were mixed with ponderosa pines at a low stocking. The ponderosa pines did not cause high mortality of shrubs until after age 14, but the last yields measured probably reflect a degree of suppression despite showing a positive flexion in growth curves at that point. Pure stands of these shrubs at the wider spacings we used would undoubtedly produce yields of large shrubs with totals greater than any measured in this study. We therefore regard these data as a beginning in understanding shrubs as a crop. While it is not unlikely that growth would continue to increase in the absence of planted conifers, the initial purpose of the study included retention of pines as the dominant crop, thus extension of production cycles beyond 14 yr may not be appropriate.

The biomass growth of whiteleaf manzanita is done at the expense of sequestering water resources needed by the conifer component (White and Newton 1989; Newton and Cole 2008), perhaps with less effect on the manzanita than on the conifers. The prediction equations (available from the corresponding author) demonstrate manzanita's potential to utilize the site resources, of which the most limiting is water. When water resources are diminished, the competitiveness of intermingled conifers is apparently reduced more because of differences in ability to extract water from bedrock (Zwieniecki and Newton 1995). The effect of manzanita competition on conifers is relatively insensitive to manzanita density (Newton and Cole 2008); hence if one is to grow mixed species, high density manzanita will provide maximum growth of this species so long as pine spacing is wide enough for shrubs to develop with adequate sunlight for a decade or more. Harvest of manzanita is likely to release the already dominant ponderosa pine (Newton and Cole 2008). The precise age for optimum harvest will need definition by experiments that evaluate harvest at different ages for different densities of pine and manzanita.

Within the manzanita stand, height growth responds to manzanita density. The best height growth occurs where manzanita density is the lowest. The least favorable height growth occurs at high densities and where herbs are not controlled. For optimum development of a whiteleaf manzanita/ponderosa mixed culture, wide spacing of pines and medium spacing of manzanita appear to have merit, especially if herbs are suppressed. Herbaceous cover is apparently able to deplete enough surface water (down to 75-cm soil depth) to impact whiteleaf manzanita, a species capable of extracting soil and rock moisture when these shrubs were 5–7 yr old at xylem pressures of −7.0 MPa. Suppression of herbs favored both pines and manzanitas.

Mortality of both Douglas-fir and manzanita may have contributed to thrift of residual shrubs. Competition from manzanita eliminated the Douglas-fir on all treatments except those with the lowest manzanita density. The ability to secure soil moisture provides manzanita with a decided survival advantage over coniferous competitors in southwest Oregon. Thus, Douglas-fir apparently had little effect on manzanita growth by depletion of soil water, but the dense foliage of Douglas-fir would, in any case, lead to suppression of this shade-intolerant shrub had water stress not interfered.

Figures 4 and 5 demonstrate the power in numbers of small shrubs. Even though individual manzanitas in dense stands are small, the high stem density produces the highest biomass per hectare as long as heavy shade is not a factor. At age 14 (1994 growing season) treatment 2 contained almost 61 percent more aboveground biomass than the next highest manzanita density. Although there was some compensatory growth on individual shrubs with each increment of spacing, biomass increment per hectare at age 14 increased with each doubling of density. As stands age and crowding sets in at wider spacings, growth differences between various spacings may merge. By age 14, the biomass of treatment 28 without herb control (13,500 stems/ha) and the next treatment density (treatment 4, with 6720 stems/ha) were virtually equal. Early herb control for four years literally doubled the biomass per shrub.

Major differences are apparent in biomass accumulation resulting from varying levels of shrub density at different ages. As in any plant population, resources per plant decrease with increases in density. The average size of an individual manzanita on treatment 2 is 2.25 kg while the average size of an individual manzanita on treatment 8 is 6.14 kg, a difference by a factor of 2.7 resulting from area of occupation 16 times larger. The aboveground biomass of individual manzanita plants relates to the crown cover. The observed differences in water use and competitive influence was remarkable in early years (White and Newton 1989) but as crowns of shrubs coalesced, differences in interaction of shrubs and pines decreased (Newton and Cole 2008).

Interaction with overstory ponderosa pine likely compromises long-term projection of manzanita growth. We observed evidence of pine release with removal of manzanita at age 21 (Newton and Cole 2008) and also observed deteriorating condition of manzanita as conifers gained in dominance after age 20. Yet shrub stands in the vicinity now over 70 yr old were dominated by very large individual manzanita shrubs even though within the range of ponderosa pine seedfall. These sites were clearly totally occupied for most of their age span. We postulate that where pine and manzanita are to be managed as mixed stands, harvest or other removal of the shrubs roughly 15 yr after establishment will allow the conifers to develop into a productive overstory. Conversely, if manzanita is managed in pure stands, it may be feasible to grow the shrubs to much higher volumes in a longer rotation in order to increase yield per hectare per year and minimize harvest cost per unit of yield.

The growth form of whiteleaf manzanita lends itself to relatively efficient utilization of this shrub for biomass. The single stems at the base would permit severance near the ground to allow transfer into a processor of some description with little residue on the ground. Absolute conversion efficiency into usable biomass will depend on equipment development. However, the conversion of biomass to energy, based on dry weight of biomass of all above-ground manzanita, would be roughly 15–50 metric tons per hectare at age 14, depending on density of the stand, with an energy content of 0.56 to 1.86 megajoules per ha per yr of growth when grown to this age.

The data on manzanita/conifer mixtures provide valuable information for an understanding of conifer growth during the first 25 yr after plantation establishment. Manzanita is superior at commandeering moisture held at high tension in soil and rock and it can maintain an expansion in biomass extending to an age when mixed hardy conifers begin to reach commercial size. Whereas the impact of manzanita on conifer growth during these years is substantial, this study demonstrates an opportunity to harvest a crop of manzanita biomass early in a rotation while leaving dominant and released ponderosa pine to produce a commercial harvest later.

This experiment indicates that biomass accumulation by manzanita is greater than that of conifers that co-exist with the shrubs for over a decade. A shrub that can accumulate 40+ tons per ha in 14 yr on sites of marginal productivity for conifers represents a significant source of fuel, both for commercial exploitation as a biofuel or extractive source, or for hazard of wildfire. Fire-risk shrub stands are presently being treated at substantial cost with massive machinery to reduce risk of catastrophic fires near homes and highways. Equipment similar to that used for reduction of fuel in this way is evidence that similar equipment could harvest the manzanita in forms useful for power generation or even commercial heating facilities. Whiteleaf manzanita does not sprout; harvest of the shrubs before the mixed conifers succumb offers an opportunity to facilitate long-term conifer production while making an asset of a major competing species.

CONCLUSIONS

Sclerophyllous shrubs in southwestern Oregon and California represent a large source of biomass of potential importance as: a) a source of fuel or fiber, b) a severe fire hazard, or c) an obstacle to conifer regeneration on moderately productive sites. Whiteleaf manzanita, as a representative of this community, will accumulate several tons per hectare per year which, if accumulated for decades, represents a fuel load capable of intense heat if not utilized or controlled.

This paper presents the first yield equations for whiteleaf manzanita growing under variable densities in a plantation environment in southwest Oregon. Yields per hectare per year are greater than those of juvenile conifers even when conifers dominate the site in the first decade. The lost early volume growth of conifers attributable to competition is offset during the first decade-plus, more or less, by increasing manzanita production. We expect plantation dynamics to shift toward the conifer component with mechanical removal of the shrubs as per Newton and Cole (2008). This will vary in time and intensity depending on the initial manzanita density. The conifer component does not appear to have the ability to overcome this initial growth loss during the first few decades, and pinpointing optimum timing for harvest of shrubs with release of conifers needs refinement.

As biofuels gain in value, potential yields of shrub communities, mixed stands and associated tree species will gain in importance. Developing an ability to accurately predict shrub and conifer productivity, growing in pure stands and mixtures on such harsh sites represents a new area in forest mensuration that has yet to be addressed.

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